

Presentation for  
Total Design Solutions Midwest Conference,  
Oct. 10, 2002  
Cleveland I-X Center

Advanced High-Temperature Seal Development at NASA  
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NASA Glenn Research Center is developing advanced seals to meet the demands of next generation aircraft and rocket propulsion systems. Dr. Steinetz will summarize NASA Glenn's efforts of developing seals that can operate from ambient through rocket exhaust temperatures (>2000°F) without cooling and summarize the extensive test capability used to qualify seal performances under these extreme conditions. NASA programs benefiting from this research, that will be reviewed, include advanced commercial and military aircraft, the Space Shuttle, the Space Station Emergency Crew Return X-Vehicle, and futuristic reusable launch vehicles. Though the seal technology is being developed for NASA and military programs, there are many commercial and industrial spin-off applications.

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# **Advanced High Temperature Seal Development at NASA Glenn Research Center**

**Dr. Bruce M. Steinetz  
NASA Glenn Research Center  
Cleveland, OH**

**Total Design Solutions Midwest (Session 10)  
October 10, 2002  
IX Center  
Cleveland, OH**

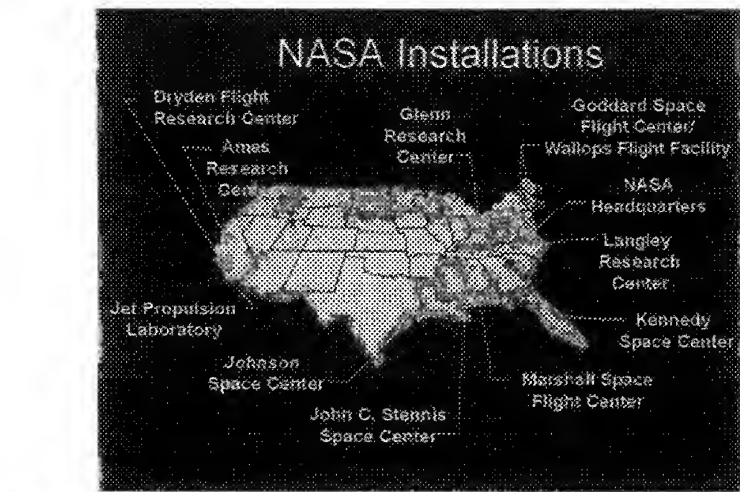
## **Contributors**

- Margaret Proctor, Irebert DelGado: Turbine Seals
- Scott Lattime: Turbine Clearance Control
- Patrick Dunlap, Jeff DeMange: Structural Seals



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## NASA Installations



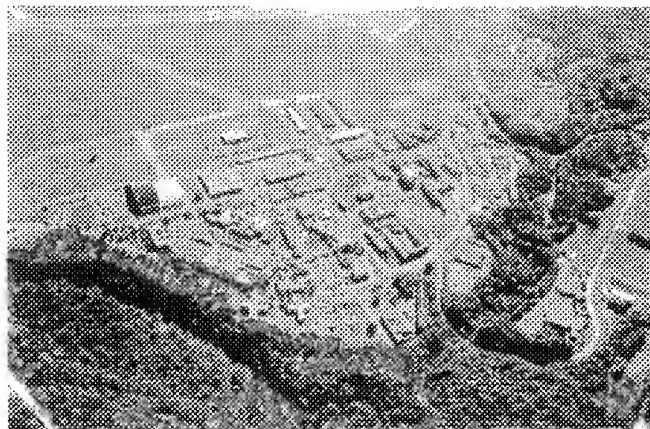
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## Glenn Research Center



- Total Workforce: 3600+      Formed as NACA 1941



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## NASA Glenn Vision

The NASA Glenn Research Center defines and develops advanced technology for high priority national needs.

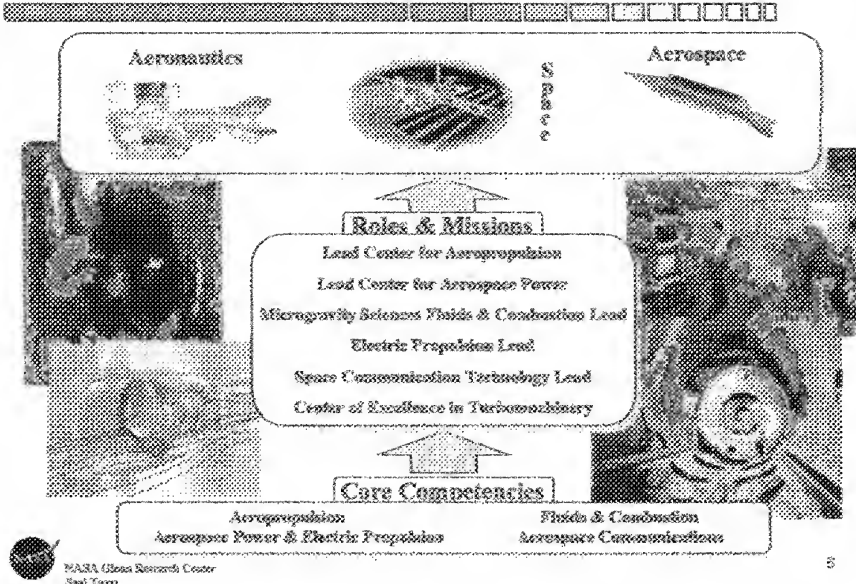
The work of the Center is directed toward new propulsion, power, and communications technologies for application to aeronautics and space, so that U.S. leadership in these areas is ensured.



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April 1999

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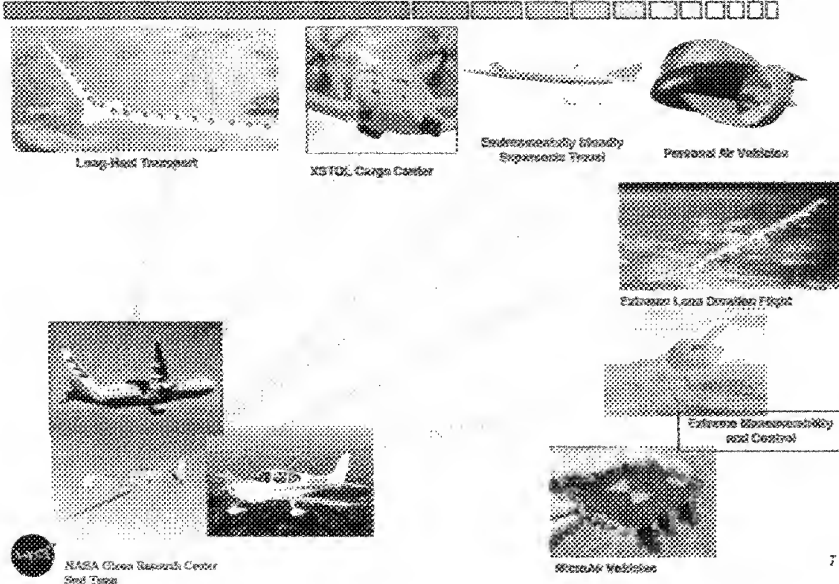
## Research and Technology Products



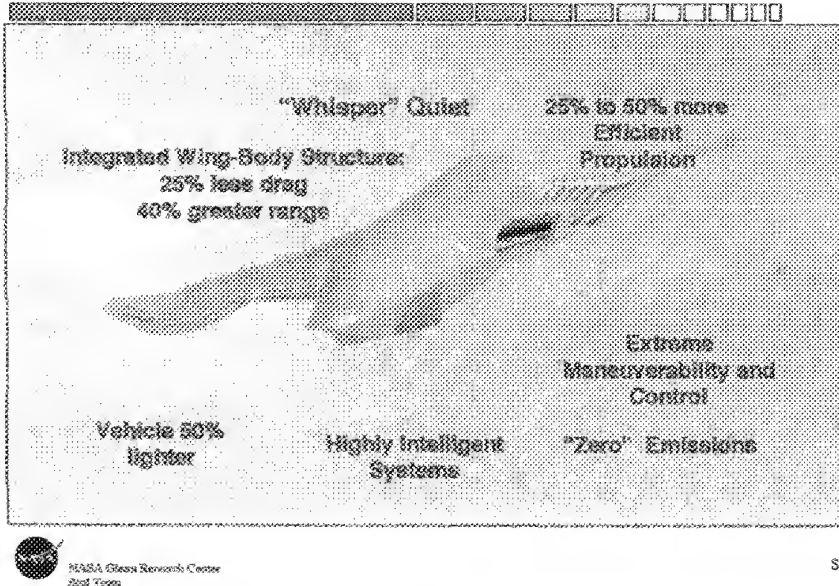
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## Revolutionary Vehicles - Multiple Paths Common Technology (graphics: incre callout point size)



## Attributes of Future Flight Vehicles



## Outline of Presentation

- Background
- Why are advanced Seals important to NASA's Mission?
- Turbomachinery seals under development
  - Shaft Seals: Brush, Finger, Aspirating, Compliant Foil Seals
  - Blade Tip Seals: Active clearance control
  - Advanced Test Facilities and Capabilities
- Structural Seals under development:
  - Ceramic Wafer Seal
  - Braided Seals: Ceramic, Hybrid
  - Knitted Spring Tube (Shuttle derived)
  - Carbon thermal barriers
  - Advanced Test Facilities and Capabilities
- Summary
- References



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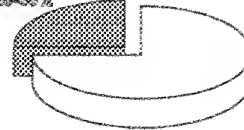
## Why Seals?

### AST Study Results: Expected Seal Technology Payoffs

Seal Technology	Study Engine/ Company	System Level Benefits
Large diameter aspirating seals (Multiple locations)	GE90-Transport/ GE	-1.8% SFC -0.6% DOC+1
Active Clearance Control (HPT)	Large Commercial/ GE/ASA	-1-2% SFC
Film riding seals (Turbine inter-stage seals)	Regional-AE3007/ Allison	> -0.5% SFC > -0.5% DOC+1
Advanced finger seals	AST Regional/ Honeywell	-1.6% SFC -0.7% DOC+1

**UEET Program Goal!**  
Reduce Fuel Burn by 8-15%

Seals  
25-35%



- Seals provide high return on technology \$ investment
  - Same performance goals possible through modest investment in the technology development
  - Example: 1/25th to 1/40th cost of obtaining same performance improvements of re-designing/re-qualifying the compressor
- Seal contribution to program goals: 2 to 3% SFC reduction

**Advanced Seal Technology: An Important Player**



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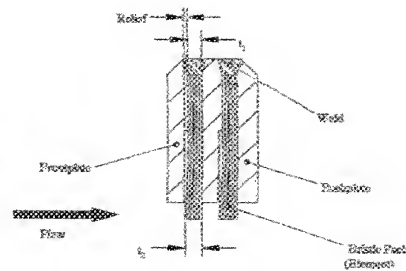
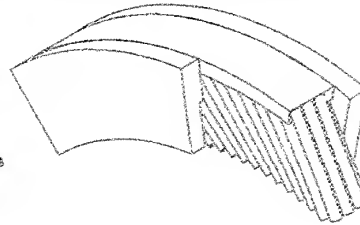
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## Brush Seals: Overview

Graphics Add color

Add recess in back

- Prior Art: Labyrinth Seal
- Design Attributes:
  - 1/5th the leakage of labyrinth seal
  - Thin seal construction packages well in small design envelope
  - Pressure closing effect urges bristles toward shaft improving seal effectiveness
  - Flexible bristles accommodate shaft movements
  - Commercially available from several vendors (Perkin-Elmer, Cross Ltd, Technetics)
- Design Considerations:
  - Cost is approximately equal to labyrinth seals. Cost for aerospace grade 8.5" dia. seal = \$XXXX each
  - Improperly designed interference can lead to shaft heating and possible negative consequences.



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## Brush Seal: Detail

Add Seal Photograph

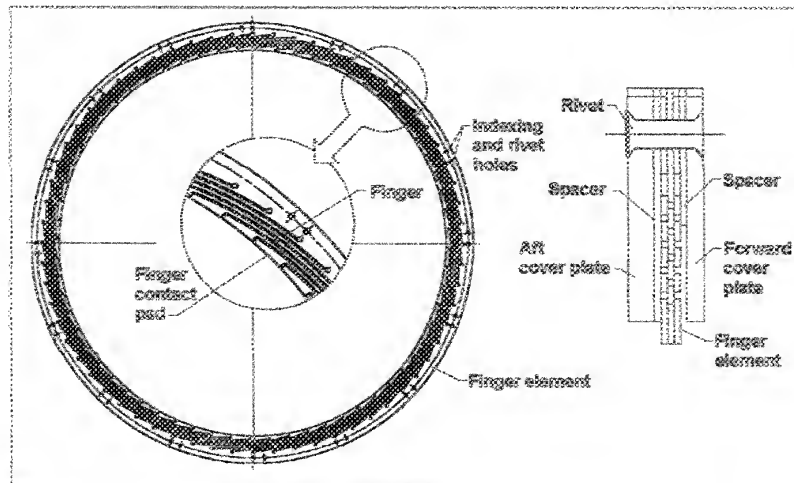
- Applications
  - Aircraft engines, ground based turbines, XXX
- Leakage
  - Effective Leakage Gap
  - Flow Modeling reference (ASME Ref style, author, year)
- Typical Materials
  - Haynes 25 Bristles (Cobalt based)
  - Inconel 718, 625 check Front plate and backing plate. Welded construction.
  - Xxx Flexi-front cover
  - Aerospace Applications
    - » Shaft generally coated with hard face coating (e.g. Chrome Carbide)
  - Ground base turbines:
    - » Shaft generally uncoated (thicker shaft walls, less issue with wear induced cracks)
- Media Sealed
  - Air, steam, limited data for Oil
- Operating Conditions Current (Future)
  - Pressure Range: 100 psi (400 psi)
  - Gas Temperature : 1200 F (1800F)
  - Surface speeds: 1200 fps (1600 fps)



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## Finger Seal Design



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cm-22212 4

## Finger Seals: Overview

- Prior Art: Labyrinth Seal
- Design Attributes:

Seal  
Image

- Design Considerations:
- Reference: Arora, G.K; Proctor, M.P; Steinetz, B.M. Delgado, I.R., 1999, " Pressure Balanced, Low Hysteresis, Finger Seal Test Results" NASA TM-1999-209191, AIAA 99-2686.

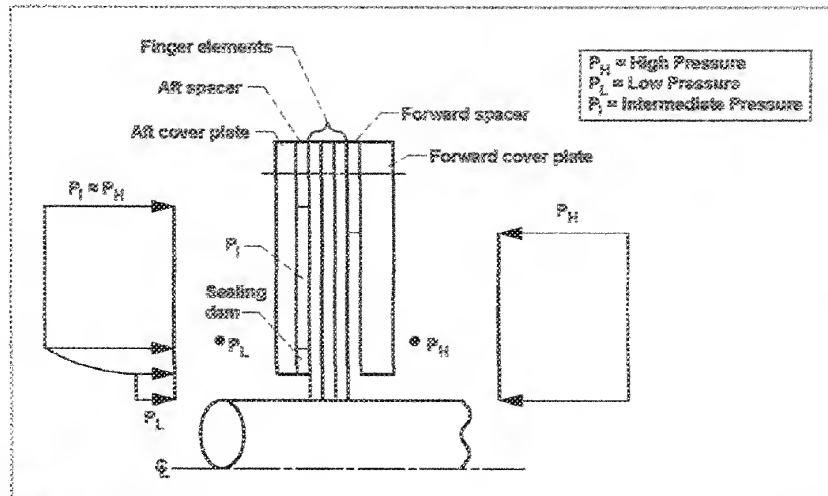


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## Pressure Balanced Finger Seal Force Balance



CP-62294-23

## Brush/Finger Seal Design Considerations

### Mechanical:

- Pressure Capability
- Frequency
- Seal Leakage
- Seal Stiffness
- Seal blow-down (e.g. pressure closing)
- Bristle tip forces and pressure stiffening effect
- Rotor dynamics
- Metal fatigue: HCF and LCF
- Reverse rotation

### Thermal:

- Seal heat generation (esp. for high temp. applications)
- Friction induced heating of flow passing through seal
- Bristle tip temperature
- Rotor thermal stability
- Secondary flow and cavity flow

## Brush/Finger Seal Design Considerations (cont'd)

### Materials/Life:

- Oxidation
- Creep
- Tribological performance:
  - Friction
  - Horsepower consumed
  - Wear (rotor and seal)
- Solid particle erosion
- Seal upstream protection
- Overall life and replacement interval



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## Aspirating Seals: Overview

- Prior Art: Labyrinth Seal
- Design Attributes:
  - Leakage < 1/5th labyrinth seal
  - Operates without contact under severe conditions:
    - » 10 mil TIR
    - » -0.25"/0.8 sec tilt maneuver loads
    - » (0.08" deflection)
  - Decrease SFC by 1.85% for three locations
- Design Considerations:
- Reference: Tumquist, NA; Tseng, T.W.,  
McNickle, A.D; Steinetz, S.M. 1999, "Full  
Scale Testing of an Aspirating Face Seal with  
Angular Misalignment," AIAA-99-2662.

Seal  
Image



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## Aspirating Seal Development: GE90 Demo Program Funded UEET Seal Development Program

### • Goal:

- Complete aspirating seal development by conducting full scale (28 in. diameter) rotating seal demonstration tests in GE90 engine.

### • Payoffs:

- Leakage <100% labyrinth seal
- Operates without contact under severe conditions:
  - 10 mil TOR
  - 0.35"/0.5 sec 18 maneuver loads (0.55" deflection)
- Decrease SFC by 1.55% for those locations

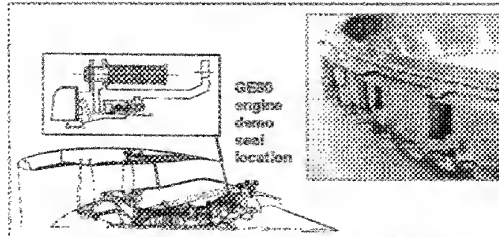
### • Schedule:

- Design and analysis by 1Q FY91 (Complete)
- Hardware fabrication by 3Q FY91 (Complete)
- Static closure test 4Q FY91 (Complete)
- GE90 engine test from 1Q to 2Q FY92
- Data analysis and report by 3Q FY92

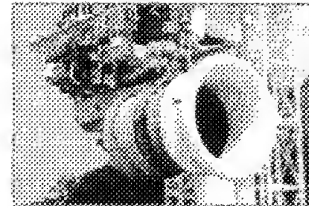
### • Partners:

GE/Win Seal/CFD/CRNASA SRC

### Aspirating Seal



### General Electric GE90



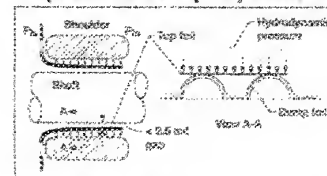
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Step 1/2/92

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## Compliant Foil Seals: Overview

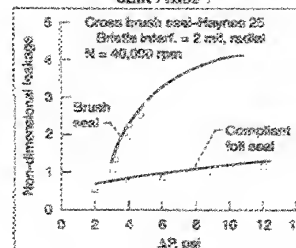
- Prior Art: Labyrinth Seal
- Design Attributes:

### Compliant Foil Seal (CFS) Schematic



- Design Considerations:

### Foil Seal and Brush Seal Leakage Data 2.84 in. Diam. Journal; 65 °F SEER Phase 1



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## Why HPT Tip Clearance?

### Specific Fuel Consumption/Fuel Burn

- 0.010-in tip clearance is worth ~ 1% SFC
- Less fuel burn, reduces emissions

### Service Life

- Deterioration of exhaust gas temperature (EGT) margin is the primary reason for aircraft engine removal from service.
- 0.010-in tip clearance is worth ~10 °C EGT.
- Allows turbine to run at lower temperatures, increasing cycle life of hot section and engine TOW ( $\geq 1000$  cycles).
- Maintenance costs for overhauls can easily exceed \$1M.

### HPT Reaps the Most Benefit Due to ACC

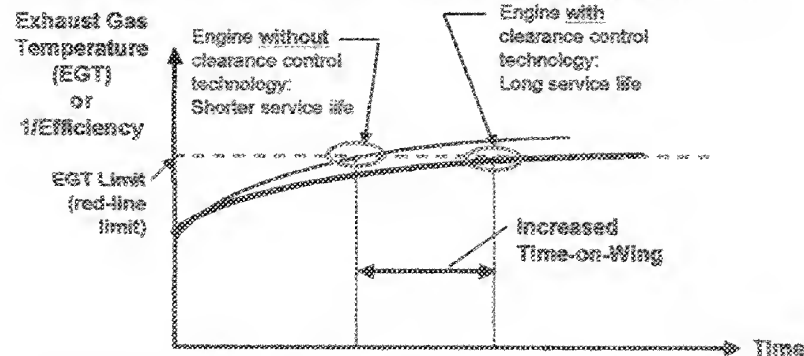
- Improved tip clearances in the HPT resulted in LCC reductions 4x>LPT and 2x>HPC. (Kawecki, 1979)



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## Active Clearance Control Technology Promotes High Efficiency and Long Life



### Current:

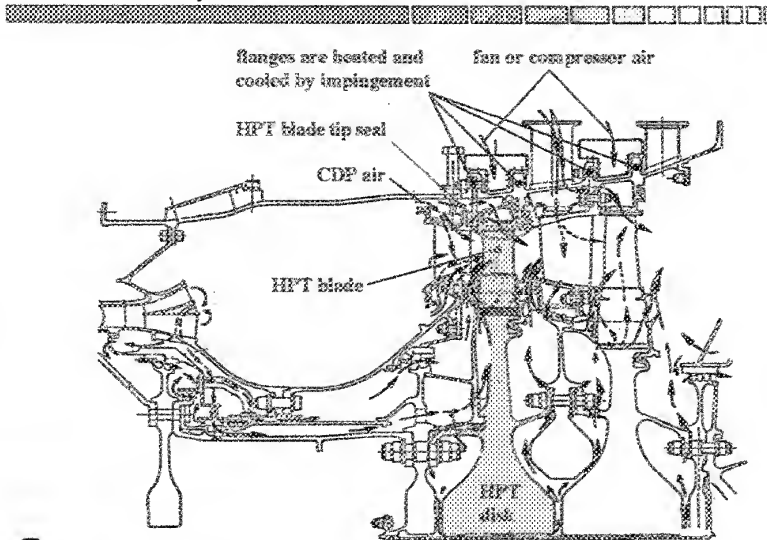
Degradation of blade tip clearances cause significant performance and efficiency loss that leads to exceeding EGT limit, thus requiring expensive engine servicing



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## HPT Blade Tip Seal Location



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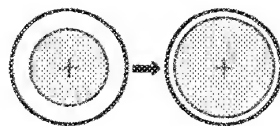
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## Mechanisms of HPT Tip Clearance Variation

1. Engine loads (centrifugal, thermal, internal engine pressure, and thrust)
2. Flight loads (inertial, aerodynamic, gyroscopic)

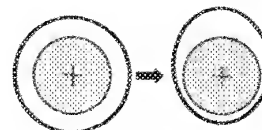
### Axisymmetric Clearance Changes

- Centrifugal, thermal, internal pressure loads that create uniform radial displacement



### Asymmetric Clearance Changes

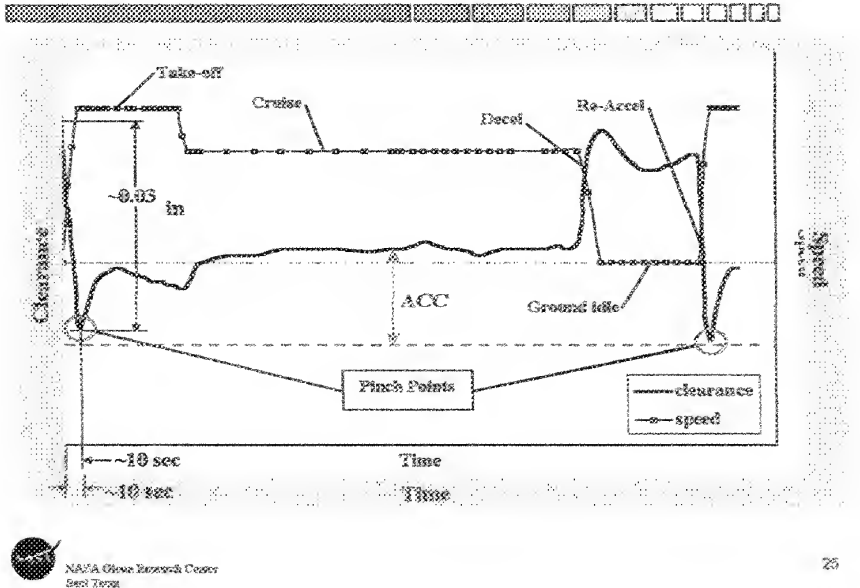
- Thermal, thrust, inertial, and aerodynamic loads that create non-uniform radial displacement



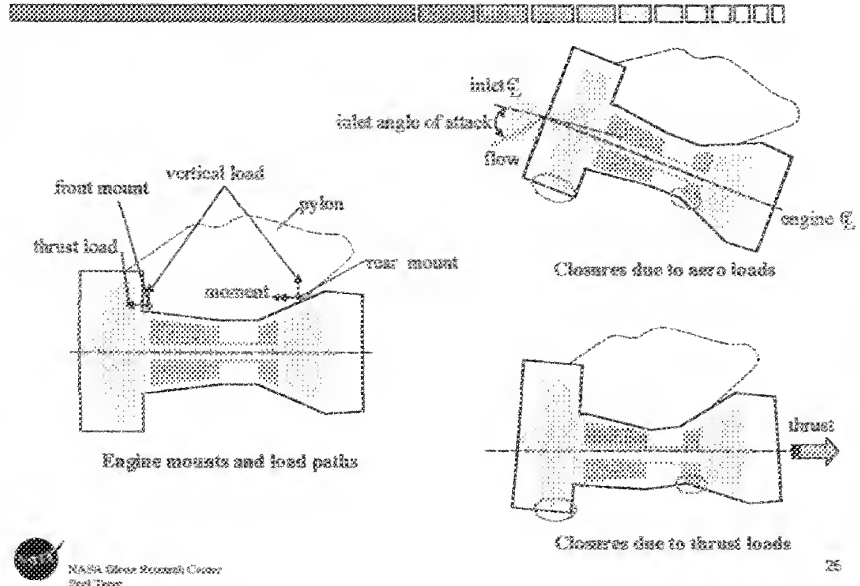
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## Axisymmetric Clearance Changes Due to Centrifugal & Thermal Loads



## Asymmetric Clearance Changes Due to Aero & Thrust Loads



## HPT Blade Tip Clearance Management Concepts

### Control Schemes:

1. Active Clearance Control (ACC) -desired clearance at multiple operating points.
2. Passive Clearance Control (PCC) -desired clearance at one operating point.

### Categories of Clearance Management Concepts

1. Active Thermal
2. Active Mechanical
3. Passive Thermal
4. Active Pneumatic
5. Passive Pneumatic
6. Regeneration



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## HPT Blade Tip Clearance Management Concepts Cont'd

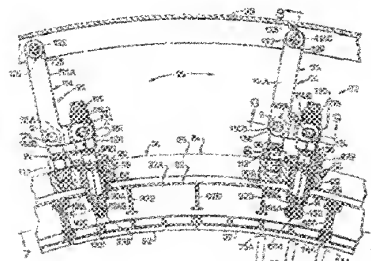
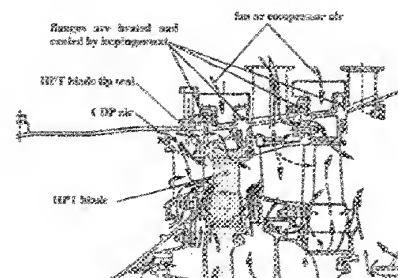


FIG. 6

Active Mechanical  
(Cortright & Pitzche, 1982)

### Active Thermal (K7, 1982)



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## HPT ACC Requirements

Actuation	
Range	~0.05-in
Rate	~0.01-in/s (per FAA takeoff requirement)
Positional Accuracy, Concentricity	~0.005-in
Force	>1000 lbs per segment (shroud cooling and purge)
Environment	
Inlet Rotor Gas Temperature	2500-3000 °F
Shroud Backside Temperature	1200-1300 °F
Case Metal Temperature	500-700 °F
Air Temperature Outside Case	100-300 °F
Shroud Backside Pressure	~500 psi
Shroud I.D. Pressure	~300 psi
Radial_P Across Shroud	~150 psi



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## HPT ACC Requirements Cont'd

Sensor	
Accuracy	~0.001-in
Response	~50kHz
Debris Tolerant	moisture, dirt, combustion products
Service Life	
On-Wing Maintenance	e.g., flight checkout/ sensor calibration
Failsafe	redundancy, biased open, and health monitoring



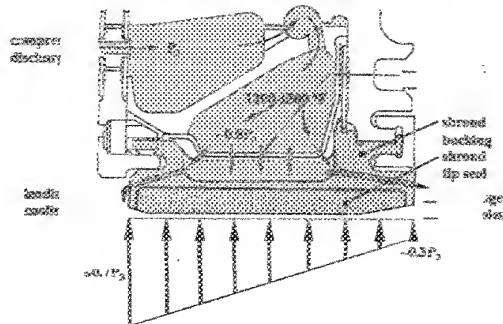
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## Actuator Force Due to Shroud Cooling and Purge

- A radial pressure difference exists across the shroud due to backside cooling ( $P_3$  air).
- Must maintain a positive backflow margin (purge) from the rotor inlet air.
- Pressure inside the shroud varies axially due to the work extracted by the turbine blades.
- An ACC system must be able to overcome this load as well as the resultant moment created by the non-uniform axial pressure distribution.



Example:  
 Shroud I.D. 30 in. width 2 in.  
 ave.  $p = 120$  psi  
 ca. 240 lbf/in on the shroud diameter  
 no. of shroud segments 15, 1 in. long  
 9 x 1.440 lbf per segment



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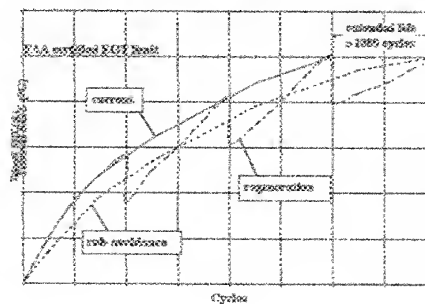
## Approaches Under Investigation & Benefits

### Fast Response ACC System

- Avoid rub-induced wear, possible erosion compensation, reduce SFC and EGT with reduced clearance.
- Utilize robust actuators coupled with precise positioning system.
- Employ high temperature clearance sensors (i.e., capacitance, microwave) —under development.

### Regenerative Tip Seal System

- Utilizes specially engineered material systems that undergo permanent volume change to restore worn clearances (rubs and erosion).
- Reduce SFC and EGT with restored seal.
- Passive (i.e., thermal) and active (i.e., thermal, voltage potential) control.



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## Turbine Seals: Advanced Test Rig



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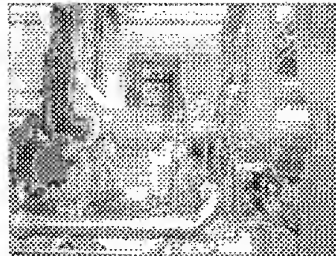
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## NASA GRC High Temperature Turbine Seal Test Rig



Goal: Test turbine seals at speeds and temperatures envisioned for next generation commercial, military, and space launcher (TBCC/RTA) turbine engines.

- Temperature Room Temperature thru 1600 °F
- Surface Speed 1600 fps at 40,455 RPM, 1600 fps at 43,140 RPM
- Seal Diameter 3.5" design; other near sizes possible
- Seal Type Air Seals: brush, finger, labyrinth, film riding rim seal
- Seal Pressure 100 psi at 1600 °F; Current (Higher pressures at lower temperatures)
- Motor Drive 90 HP (60,000 RPM) Barbour Stockwell Air Turbine with advanced digital control for high accuracy/control
- Financial Support: USHT, SEC, Air Force, Other



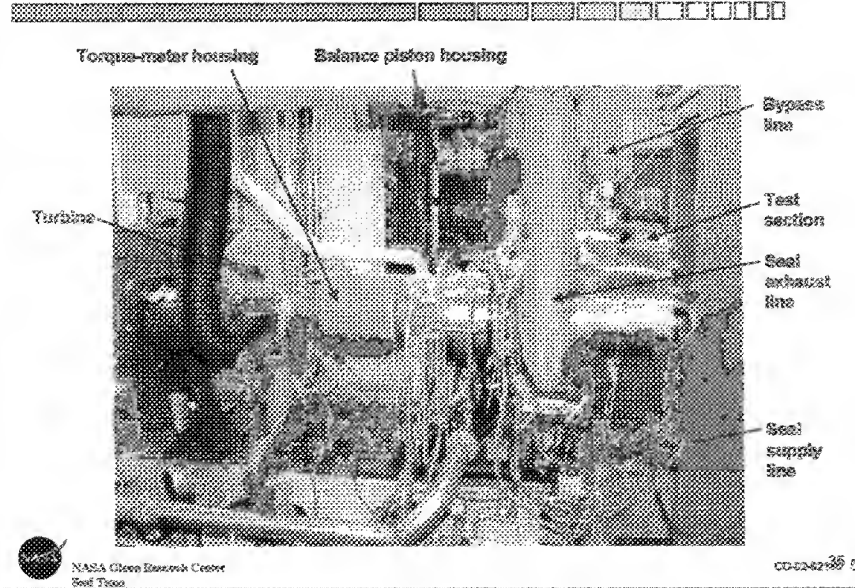
Test rig is one-of-a-kind. More capable than any known test rig in existence.



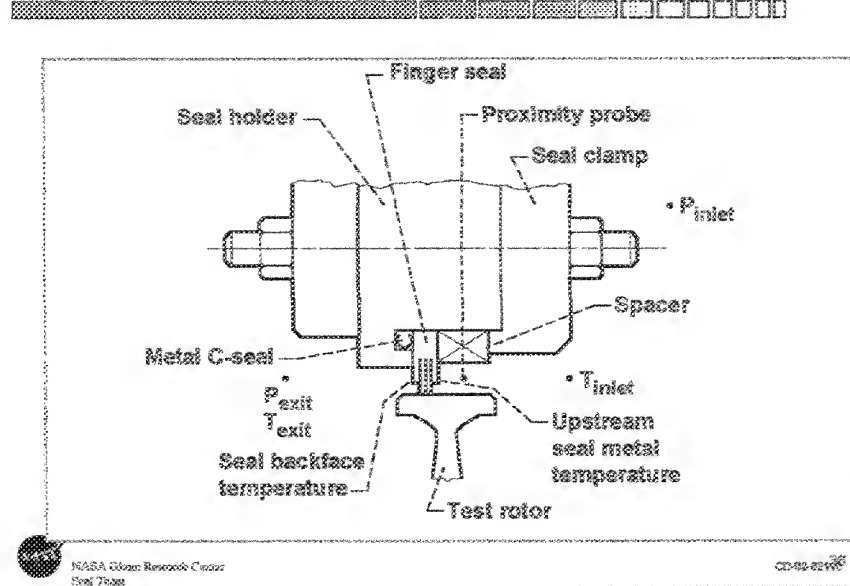
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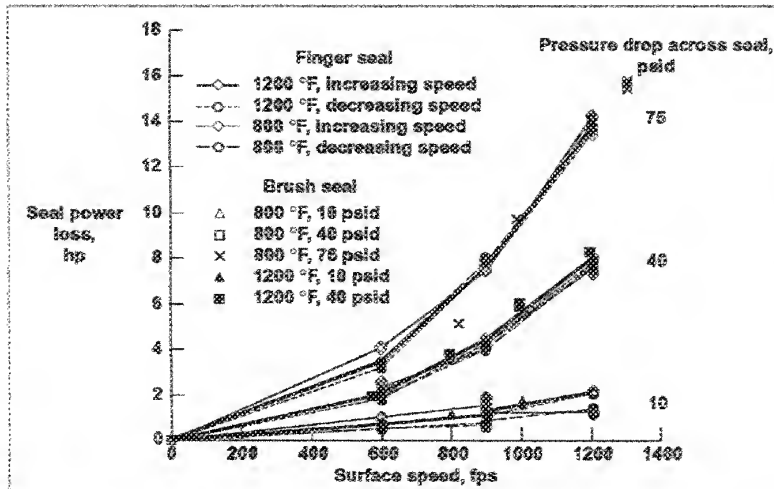
## High-Temperature, High-Speed Turbine Seal Rig



## Test Seal Configuration and Location of Research Measurements



## Comparison of Finger Seal and Brush Seal Power Loss Data

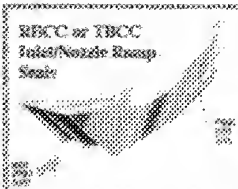
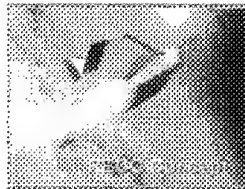


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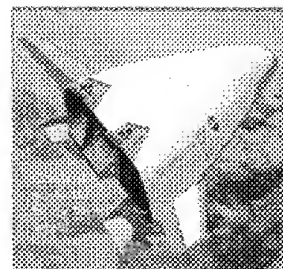
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## NASA Glenn High Temperature Structural Seal Development for 3rd Generation Space Transportation Programs

- Develop hot (2000–2500 °F), flexible, dynamic structural seals for ram/scramjet propulsion systems (RBCC, TBCC, GTX)



- Develop reusable re-entry vehicle control surface seals to prevent ingestion of hot (8000 °F) boundary layer flow



Hot, dynamic seals critical to meeting 3rd generation program life, safety, and cost goals



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## Seal Development Motivation and Objectives

- Why is advanced seal development important?
  - Seal technology recognized as critical in meeting next generation aero- and space propulsion and space vehicle system goals
  - Large technology gap exists in Hypersonic Investment Area for both control surface and propulsion system seals:
    - No control surface seals have been demonstrated to withstand required seal temperatures (2000-2500°F) and remain resilient for multiple temperature exposures while enduring scrubbing over rough sealing surfaces
    - No propulsion system seals have been demonstrated to meet required engine temperatures (2500+°F), sidewall distortions, and environmental and cycle conditions.
- NASA GRC Seal Team leading two 3<sup>rd</sup> Generation RLV structural seal development tasks to develop advanced control surface and propulsion system seals

Goal: Develop long life, high temperature control surface and propulsion system seals with the aid of appropriate evaluation and analysis methods

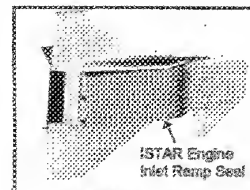


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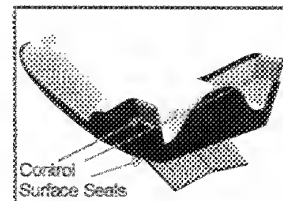
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## Structural Seal Objectives and Background

- Goal: Develop high temperature, long life, control and propulsion system seals with the aid of appropriate test/analysis methods
- Areas of Development
  - Propulsion System Seals
    - 3<sup>rd</sup> Generation Reusable Launch Vehicle
      - ISTAR Engine (RBCC)
  - Control Surface Seals
    - 3<sup>rd</sup> Generation Reusable Launch Vehicle
      - X-38 / Crew Return Vehicle
      - X-37 / Space Maneuver Vehicle



ISTAR Engine  
(P&W/Aerjet/Boeing/Rocketdyne)



X-38 CRV



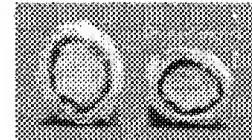
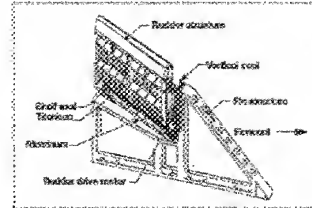
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## Performance Criteria for High Temperature Seals

### Primary Role of High Temperature Structural Seals:

- Minimize leakage
  - Propulsion System Seals: Prevent unburned fuel from leaking into backside cavities
  - Control Surface Seals: Block excessive heat flow
- ✓ Good insulatory properties → block heat flow
- ✓ Good flexibility → conform to complex airframe and propulsion system geometries
- ✓ Good resiliency → maintain contact with opposing surfaces under dynamic conditions and over many cycles
- ✓ Good wear resistance → maintain seal continuity under dynamic conditions and over many cycles



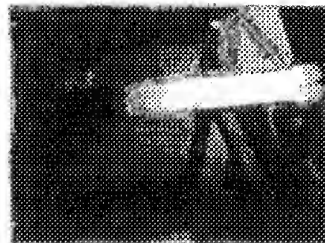
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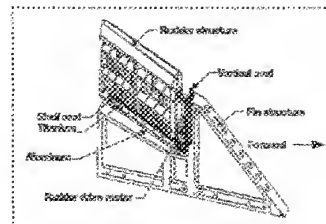
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## GRC X38 Seal Test Evaluation and Support

- Examining control surface seals for JSC for X-38 (C.R.V. demonstrator)
- Evaluated seal flow rates, compression levels, and arc jet heating resistance
- Performed furnace exposure tests on X-38 seal in compressed state at 1900°F and pre-and post-exposure flow tests:



1900 °F Furnace Tests



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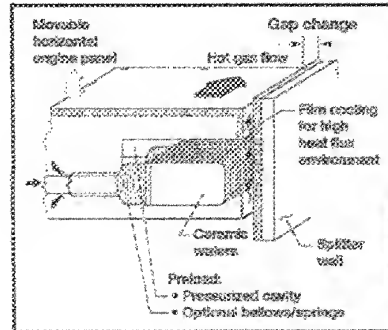
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## Ceramic Wafer Seal

- Prior Art: Metal leaf seals
- Design Attributes:

- Design Considerations:

- Reference:



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## Braided Rope Seals

- Prior Art: Metal leaf seals
- Design Attributes:

- Design Considerations:

- Reference:

Insert  
Image here



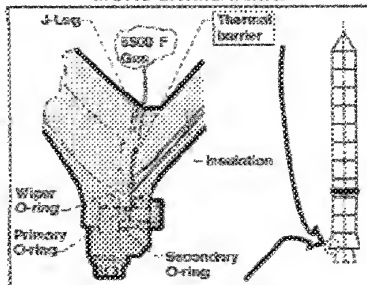
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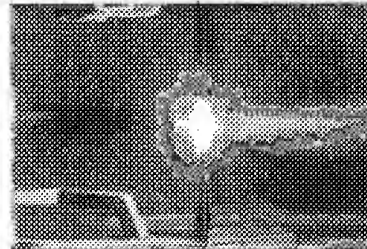
## Thiokol Selects NASA GRC Thermal Barrier for RSRM Joint Redesign

- Thiokol experiences periodic hot gas effects in RSRM nozzle-joints leading to extensive reviews before flight.
- Glenn thermal barrier braided of carbon fiber has shown outstanding ability to prevent hot (5500°F) gas from effecting downstream O-rings in multiple sub- and full-scale RSRM tests.

Redesigned RSRM Nozzle-to-Case Joint w/GRC thermal barrier



GRC 5500°F Flame Test



Thiokol has selected GRC thermal barrier for Nozzle-to-Case Joint redesign and qualifying performance for Joint Numbers 1, 2, & 5.



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CD-91-01894-000

## NASA Glenn Carbon Fiber Rope Thermal Barrier Full Scale Shuttle Solid Rocket Motor Static Tests

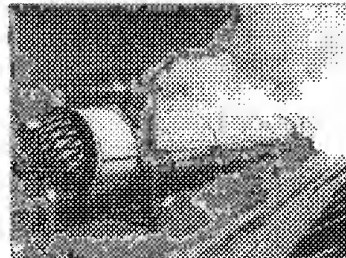
**Objective**  
Investigate feasibility of new joint designs with carbon fiber rope (CFR) thermal barrier to protect Viton O-ring seals in full-scale solid rocket motors

### Full scale motor tests

<b>FSM-9 test</b>	
Nozzle-to-case joint	1 CFR
Joint #2	2 CFRs
<b>ETM-2 test</b>	
Joint 1*	2 CFR
Joint 2**	2 CFR
Joint 5*	1 CFR

\* Replace RTV with CFR  
\*\* Demonstrate fault tolerance of CFR

Thiokol Full-Scale Solid Rocket Motor Static Test



Add movie file here

### Schedule

FSM-9	May 24, 2001	Successfully demonstrated CFR in nominal joint
ETM-2	November 1, 2001	Examine flawed & nominal joint with CFR

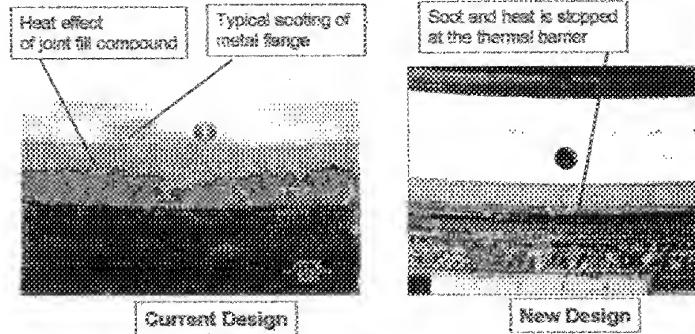


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## Elegant Solution: Carbon Fiber Rope Thermal Barrier



- Blocks heat and combustion products from entering nozzle joints
- Enables solid rocket motor joint assembly in significantly less time (approximately 1/6th time) as compared to the current joint fill compound approach
- Simplifies joint-assembly and reproducibility.
- Final qualifying full scale motor test: November, 2002
- Commence assembling in RSRM: First Quarter CY03



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## Structural Seals: Advanced Test Fixtures



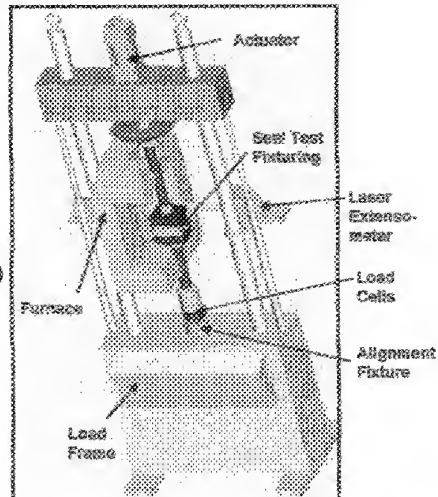
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## Hot Compression / Scrub Seal Testing Rig Overview

### System Components

- MTS Model 318.25 Servohydraulic Load Frame
  - 55 kip load frame
  - 3.3 kip, 6 in. stroke actuator
  - 229 lb, 3300 lb load cells
  - 5.5 kip alignment fixture
  - 11 gpm HPU
  - Dual servovalves (1 gpm, 15 gpm)
  - TestStar Rs controller
- ATS Series 3350 Custom Box Air Furnace
  - Temperatures up to 3000°F (1650°C)
  - Kanthal Super 33 MoSi<sub>2</sub> heating elements
  - Large working volume (30" W x 14" D x 18" H)
  - Front and back loading doors & top port
  - Adjustable laser alignment fixturing and shield
- Beta LaserMike IntelliScan 50 Extensometer
  - Non-contact Class II laser extensometer
  - 0 in. – 2 in. measurement range
  - ±0.25 mil accuracy
  - 1000 scans/s
  - Hot object filter



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CS-01-0196 4

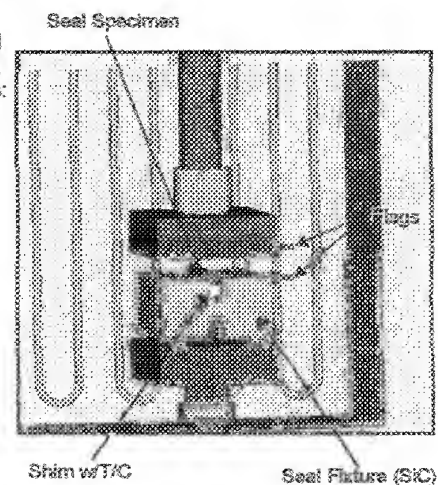
## Hot Compression Rig Details

### Purpose

- New rig will permit measurement of seal load vs. linear compression, preload, & stiffness for various test conditions:
- Temperature
  - Compression level
  - Loading rate
  - Load cycling vs. stress relaxation

### Capabilities

- ✓ Temperatures up to 3000°F (1650°C)
- ✓ Loads up to 3300 lbs
- ✓ Stroke rates from 0.001 in/s to 8.9 in/s
- ✓ Seal lengths up to 4 in.
- ✓ Seal diameters up to 2 in.
- ✓ Variety of loading waveforms
  - Cycling (sine wave, sawtooth, user-defined profiles)
  - Stress relaxation

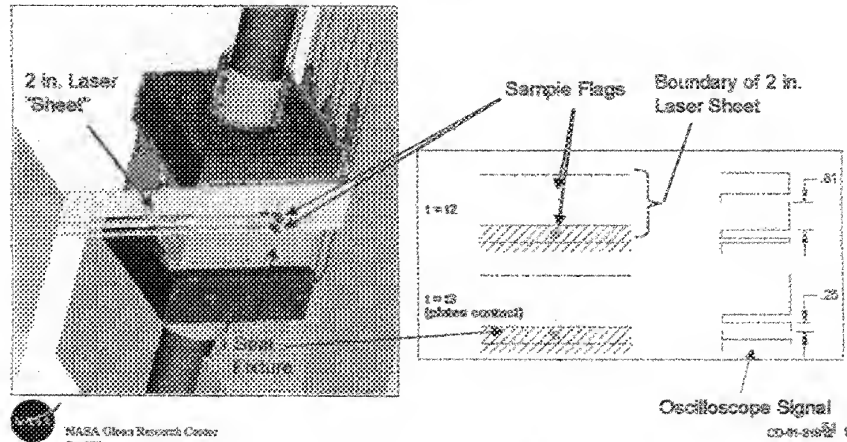


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## Hot Compression Rig Details: Laser Extensometer

- Laser extensometer will permit very accurate, high temperature, non-contact measurements of seal compression level
- Total displacement = Flag gap (t) – Flag gap (t<sub>0</sub>)



## Hot Scrub Rig Details

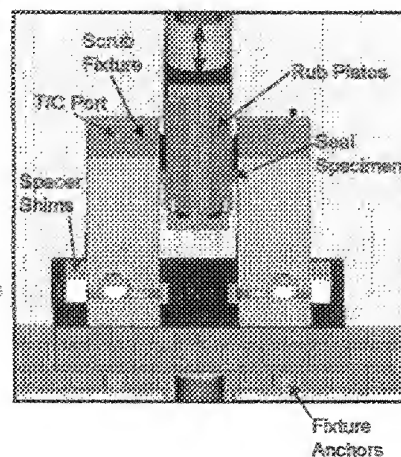
### Purpose

New rig will permit measurement of wear rates and frictional loads for various test conditions:

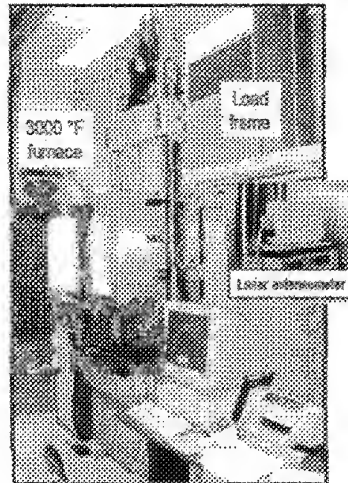
- Temperature
- Compression level
- Stroke rate and number of cycles
- Rub surface conditions (material, roughness, surface profile)

### Capabilities

- ✓ Temperatures up to 3000°F (1650°C)
- ✓ Loads up to 3300 lbs
- ✓ 3 in. stroke at rates from 0.001 in/s to 3.0 in/s
- ✓ Seal lengths up to 4 in.
- ✓ Seal diameters up to 2 in.
- ✓ Gaps from 0 in. to 1.125 in.
- ✓ Variety of cyclic loading waveforms (sine wave, sawtooth, user-defined profiles)
- ✓ Pre- & post-scrub flow testing



## Hot Compression / Scrub Seal Testing Rig



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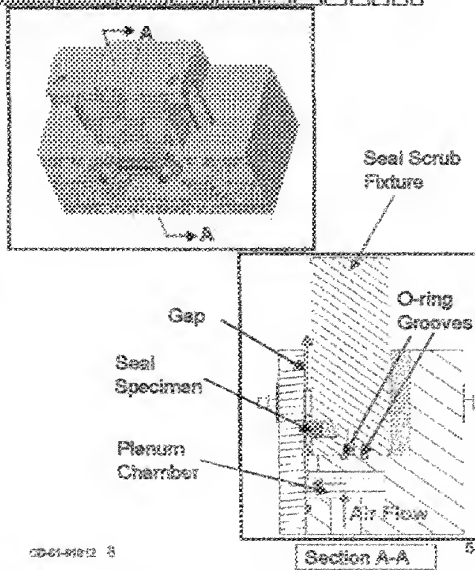
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## Hot Scrub Rig Details: Pre- and Post-Scrub Flow Testing

### Purpose

Ambient flow fixture permits pre- and post-scrub flow evaluations of candidate seals

- Flow testing at 3000°F prohibitively expensive and complicated
- Design minimizes damage due to secondary handling (seal undisturbed between scrub test and flow test)
- Modular design facilitates testing of multiple seal configurations under different testing conditions
  - Test gases: air
  - Flow rates: 0 – 3000 slpm
  - Pressures: 0 – 120 psi
  - Gap settings: 0 – 1 in.



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Section A-A

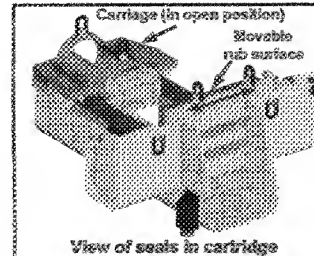
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## Ambient Scrub & Flow Testing Rig Overview

### Purpose

Combined seal flow and scrub tests will be performed in new ambient test rig. Flow rates through seals will be measured for various test conditions:

- Scrub/cycle damage
- Compression level
- Gap size
- Rub surface conditions (material, surface roughness, surface profile)
- Scrub direction (e.g., transverse vs. wiping)



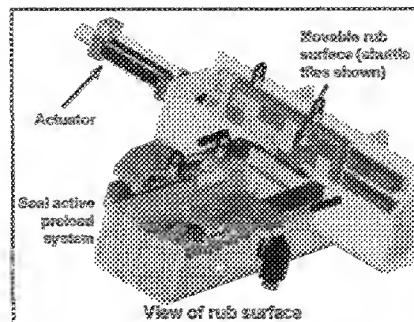
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## Ambient Scrub & Flow Testing Rig Overview (cont.)

### Capabilities

- ✓ Multiple seal geometries/configurations
- ✓ Seal lengths up to 8 in.
- ✓ Scrub rates up to 12 in/s
- ✓ Scrub loads up to 10 kip (frictional loads)
- ✓ Stroke up to 12 in.
- ✓ Active (pneumatic) or passive (Belleville washers) seal preload monitoring system
- ✓ Multiple scrub directions (cartridge can be rotated)
- ✓ Variety of rub surface conditions
- ✓ Test gas: air
- ✓ Flow rates up to 3000 slpm
- ✓ Pressures range: 0 - 120 psi



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## Sealing Trends

### Turbine Engines

- Non-contacting seals capable of low leakage and long life minimizing maintenance costs
  - Foil Face Film-Riding Seals: Munson et al
  - Compliant Foil Seals: Satehi et al
- Active clearance control to avoid blade-to-shroud rubs
  - Slow exhaust gas temperature (EGT) rise thereby increasing engine time-on-wing
  - Maintain turbine engine efficiency and decrease specific fuel consumption
  - Increase engine performance
    - » Commercial engine: range and payload
    - » Contribute to meeting NASA's turbine based combined cycle access to space goal

### Future Space Vehicle Systems

- High temperature (>2000°F), resilient, multi-use seals required for future highly reusable vehicles
  - Hot CMC control surfaces (e.g. Crew return vehicle - X-38, other)
  - Ram/Scramjet propulsion systems for future single and two stage to orbit launch vehicles concepts



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## Summary

- Seals technology recognized as critical in meeting next generation aero- and space propulsion and space vehicle system goals

- Performance
- Efficiency
- Life/Reusability
- Safety
- Cost

- NASA Glenn is developing seal technology and/or providing technical consultation for the Agency's key aero- and space advanced technology development programs.



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## Appendix



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## NASA Glenn Seals/Secondary Air Flow Workshop



### Preliminary Agenda:

- Overview and Program Needs
- Recent Seals/Secondary Air Management Developments
  - Presentations on Specific Seal Developments:  
Brush; Finger; Rim; Face; Foil; Abradable; Tip; Static Seals
  - Material Developments
  - Space Vehicle Seals
  - Related Topics
- Tour of Facilities

Date: October 23-24, 2002

Location: NASA Glenn Research Center,  
Ohio Aerospace Auditorium (outside NASA's back gate)

Invitation: Provide me Business Card if you desire invitation

Open to U.S. Citizens Only and Permanent Legal Residents



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## NASA Seals Web Sites

- Turbine Seal Development

<http://www.grc.nasa.gov/WWW/TurbineSeal/TurbineSeal.html>

NASA Technical Papers

Workshop Proceedings

- Structural Seal Development

<http://www.grc.nasa.gov/WWW/structuralseal/>

NASA Technical Papers

Discussion



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## Notes to Graphics

- Use bullets/sub-bullet master template that I started
- Use consistent font and pt size for all chart titles.
- Insert movie files where indicated
- Output:
  - Power point presentation w/movies embedded
  - TBD (~25-40) B&W hand out pages (2 slides per page)
  - 1 set Color viewgraphs (as back-up in case projector fails)



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## Flow Factor

$$\Phi = \frac{\dot{m} \sqrt{T_{avg} + 459.60}}{P_u \times D_{seal}}, \quad \frac{\text{lbm-in.} \sqrt{^\circ\text{R}}}{\text{lbf-s}}$$

where

$\dot{m}$  Air leakage flow rate, lbm/sec  
 $T_{avg}$  Average seal air inlet temperature,  $^\circ\text{F}$   
 $P_u$  Air pressure upstream of seal, psia  
 $D_{seal}$  Outside diameter of the seal rotor, in.



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## References



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